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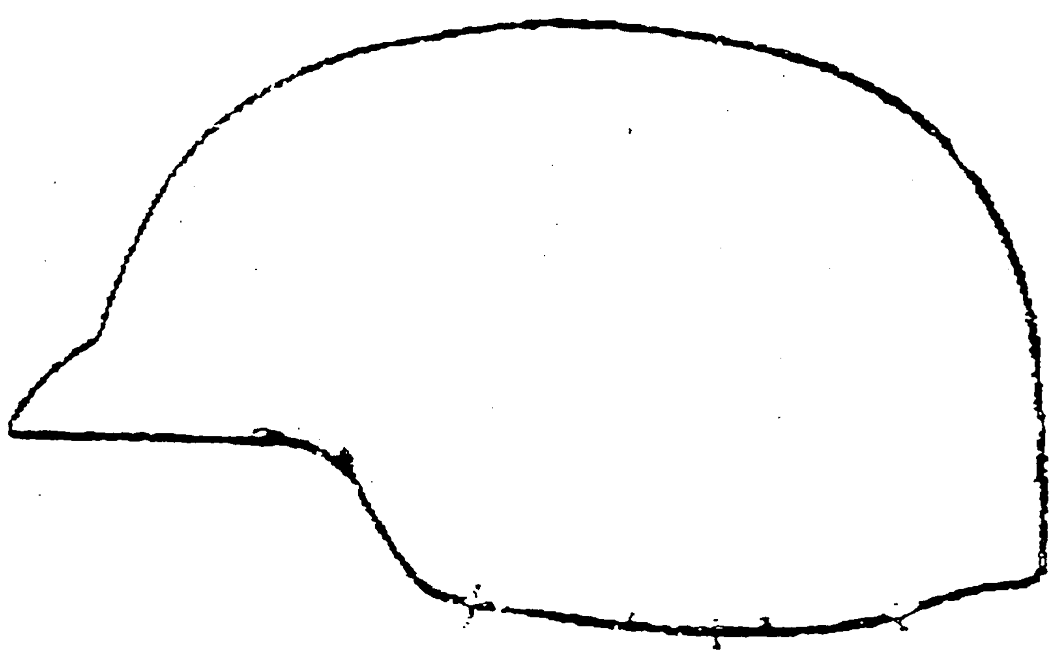
(54) Title: CONTOUR RIGID COMPOSITE STRUCTURE AND METHOD



(57) **Abstract:** A contoured multilayer laminated composite structure having uniform surface area before, during, and after processing, thereby providing improved and uniform finished product characteristics and performance for protective body armor and/or sporting goods applications. The contoured rigid laminated structure of the present invention provides increased impact resistance, resistance to delamination, shear resistance, strength, and overall performance due to the uninterrupted dissipation of energy spread throughout the entire surface area of the fabric and the uniform surface area presented in the finished product.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

CONTOUR RIGID COMPOSITE STRUCTURE AND METHOD

Cross-References to Related Applications

This application is related to copending applications, having related subject matter but not claiming priority therefrom, having common assignee including 60/197,466 entitled MILITARY HELMET filed on 04/17/2000.

Background of the Invention

(1) Field of the Invention

The present invention relates generally to the composite structures and applications thereof, more particularly, to contoured rigid composite structures including multilayer laminate fabrics and methods for making same.

(2) Description of the Prior Art

In general, it is known in the art to mold concave structures such as helmets using multiple layers of laminated fabrics that are combined with a resinous treatment for consolidation of the layers. Additionally, it is known in the art to use high performance fibers to improve the characteristics of the composite structure, including impact resistance and strength. However, overall, these and related systems fail to prevent delamination between the multiple layers of fabric used to form the molded concave structure. Because many layers of fabric are necessary to provide a predetermined minimum strength, impact resistance, ballistic resistance, and shear resistance, there remains a need to construct and configure a multilayer laminated composite structure molded into concave and other contoured shapes such that the overall composite structure can resist delamination during handling in manufacturing and use.

Furthermore, when fabricating concave and other contoured shapes using a multilayer laminated perform, triangular cut-out regions were required for each layer of

fabric to avoid fabric bunching, creasing, and/or non-uniform overlap areas during processing, which remain in the final product, creating uneven surfaces and non-uniform performance characteristics in those regions. Typically, the triangular cut-out regions are positioned in predetermined locations whereby the surface area of each fabric layer resembles a pinwheel shape. The pinwheel cuts require additional processing time to form, as well as to position each layer during lamination such that the triangular cut-out regions are not juxtapositioned directly or nearly above or below another cut-out region. Thus, there remains a need for a contoured, multilayer laminated structure having uniform surface area before, during, and after processing, thereby providing improved and uniform finished product characteristics and performance.

Unlike prior art helmets made using pinwheel cuts, the contoured rigid laminated structure of the present invention provides increased impact resistance, resistance to delamination, shear resistance, strength, and overall performance due to the uninterrupted dissipation of energy spread throughout the entire surface area of the fabric and the uniform surface area presented in the finished product. The transfer of energy is uninterrupted and other performance characteristics of the multilayer contoured laminate structure of the present invention because no seams, creases, wrinkles, or non-uniformities are present in the fabric performs before, during, or after lamination, treatment, and molding to form the finished product. Moreover, the absence of seams provides increased resistance to delamination.

Additionally, prior art teaches the use of resinous treatment or coating in combination with multilayer laminated structures to improve delamination resistance. However, any and all resinous treatments, even after setting and curing, merely provide

amorphous bonding between laminated layers, which continue to be subject to delamination, reduction of strength and impact resistance in those amorphous regions.

Summary of the Invention

The present invention is directed to a contoured multilayer laminated fiber composite structure having resistance to delamination, high strength and impact resistance, and shear resistance. Additionally, the invention is directed to a method for making the same. The invention is applicable to military helmets having ballistic resistance. Additionally, the invention is applicable to sporting goods, including but not limited to boats, canoes, skateboards, surfboards, coolers, and protective wear including helmets, knee and elbow protective coverings or shields, and the like. Advantages of the invention include lightweight, moldable multilayer laminated performs that do not crease, wrinkle, fold, or overlap to create non-uniform surface regions before, during, or after processing; as such, the present invention provides superior structural uniformity and performance characteristics. Also, the method of manufacturing contoured multilayer laminated fiber composite structures according to the present invention does not require patterning, creating cut-out regions or overlapping material within a given fiber layer in order to conform to a predetermined contoured shape. Furthermore, the contoured composite structure according to the present invention may be molded, compression molded, pressed, or otherwise manipulated into a contoured shape without delamination, creasing, folding, or making non-uniformities within layers forming the laminated structure.

Accordingly, one aspect of the present invention is to provide a contoured multilayer laminated fiber composite structure for applications requiring substantially

uniform characteristics across all contoured areas of the composite structure. Another aspect of the present invention is provide a contoured multilayer laminated fiber composite structure for use in a military helmet having ballistic resistance. Additionally, it is an aspect of the present invention to provide a contoured multilayer laminated fiber composite structure for use in sporting goods, including but not limited to boats, canoes, coolers, and protective wear.

Also, it is an aspect of the present invention to provide a method for forming a contoured multilayer laminated fiber composite structure for use in body armor, protective wear, and sporting goods, wherein the structure includes a molded preform. Finally, it is an aspect of the present invention to provide a method for forming a contoured multilayer laminated fiber composite structure. Other objects and advantages of the present invention will become apparent to those skilled in the art after a reading of the following description of the preferred embodiment and the accompanying drawings which are merely illustrative of such invention.

Brief Description of the Drawings

Figure 1 is a side view of a component of a preferred embodiment according to the present invention.

Figure 2 is top view of prior art.

Figure 3 is a top view of an alternative preferred embodiment of the present invention.

Figure 4 is a side view of the preferred embodiment shown in Figure 3 constructed according to the present invention.

Detailed Description of the Preferred Embodiments

In the following description, like reference characters designate like or corresponding parts throughout the several views. Also in the following description, it is to be understood that such terms as "forward", "rearward", "left", "right", "upwardly", "downwardly', and the like are words of convenience and are not to be construed as limiting terms.

Referring now to the drawings in general and to Figure 1 in particular, it will be understood that the illustrations are for the purpose of describing a preferred embodiment of the invention and are not intended to limit the invention thereto. The preferred embodiment shown in Figure 1 shows a protective helmet, generally referenced 10, which is formed of a unitary, seamless construction using at least one layer of a 3-D woven material. A complete disclosure of this material is provided in U.S. Patent No. 5,085,252 and 5,465,760 owned by the present applicant, and incorporated herein by reference in its entirety. In the embodiment shown in Figure 1, the material provided for forming the helmet embodiment does not require any slitting or cutting at all. Basically, the material is cut to a substantially circular shape having a diameter or cross-sectional area that is sufficient to form a protective helmet to fit a human head, e.g., a generally circular or octoganol template having an approximately 20" diameter. By contrast to PRIOR ART Figure 2, slits or cuts are necessary to ensure that creasing and/or folding of the material used to form the helmet is diminished or reduced. By eliminating the need for cutting or slicing prior to molding the helmet or other contoured design, the overall strength and integrity of the final composite structure is optimized.

According to the present invention, the material or fabric is formed of at least one high-performance fiber array with a three-dimensional weave construction and at least one warp layer. The 3-D fabric is molded to form a predetermined contour shape. Also, the 3-D fabric is impregnated with a resin and cured using a conventional prepreg machine. Between about 1 and about 15 plies of the resin-coated fabric are then placed in a helmet mold. The fabric remains in the mold under pressure for approximately three minutes at 300 degrees Fahrenheit. The increased interstices of the 3-D fabric promote resin flow within the fabric and significantly reduce resin cure time.

The preferred density range for each ply of fabric is from between 0.10 lbs/sq ft to 1.5 lbs/sq ft. The preferred thickness of each ply is from between 0.03 inches to 0.36 inches. The density of 0.36 inches of fabric is 1.43 lbs/sq ft. The overall thickness of the helmet is preferably between 0.275 to 0.360 inches.

In one type of preferred embodiments, the present invention is used to form a helmet constructed of 3-D woven fabric, the finished helmet, which may be used in a military, ballistic-resistant application is best seen in Figure 5. A complete disclosure of this fabric is provided in U.S. Patent No. 5,085,252 commonly owned by the present assignee, and incorporated herein by reference, and shown in Figure 1. The 3-D woven fabric, generally referenced 10, shows three substantially perpendicular yarn systems, respectively positioned in an X direction, a Y direction, and a Z direction, as shown. The 3-D woven fabric includes at least one high performance fiber array in one of the X, Y, or Z directions. In a preferred embodiment the warp direction, or X direction, comprises high performance fibers. Alternatively, the Y and Z directions also include high performance fibers for increased impact and ballistic resistance.

In one embodiment, the fabric is formed of high-performance fiber selected from the group consisting of aramid fibers, polyolefins, ultra high molecular weight polyethylene and high molecular weight polyethylene, high modulus vinylon, and liquid crystal polymer-based fiber, and in a preferred embodiment KEVLAR 129, with a three-dimensional engineered fiber construction of between about 10 to about 30 ends per inch, preferably about 20 ends/inch, between about 15 to about 35 picks per inch, preferably 25 picks/inch, and between about 1 to 5 warp layers, preferably 2 warp layers. Other high-performance fibers having a tensile strength of greater than about 5 grams per denier may be used; preferably, the high performance fibers have a tensile strength of greater than 7 grams per denier. The engineered fiber construction may be woven, multiaxial, braided, non-woven, or similar means of constructing multilayer fiber arrays within an integrated fabric body.

Between about 1 to about 15 plies of the resin-coated fabric are then placed in a predetermined contoured mold for forming the overall shape and configuration of the contoured laminated multilayer composite structure. The fabric remains in the mold under pressure for between about one to about six minutes, preferably approximately three minutes at between about 150 to about 350 degrees Fahrenheit, preferably about 200 to about 250 degrees Fahrenheit. Importantly, the increased interstices of the 3-D fabric promote resin flow within the fabric, uniform resin distribution throughout the contour-shaped fabric, and significantly reduce resin cure time. The resin type will influence the time and temperature required for cure. In some cases, ambient curing is effective.

The preferred density range for each ply of fabric is from between about 0.05 lbs/sq. ft. to about 2.0 lbs/sq. ft., preferably between about 0.10 lbs/sq ft to about 1.5 lbs/sq ft. The preferred thickness of each ply is approximately between about 0.02 inches to about 0.42 inches, preferably between about 0.03 inches to about 0.36 inches. In a preferred embodiment wherein the fabric thickness is about 0.36 inches the density of the fabric is about 1.43 lbs/sq ft. Where the contoured laminated multilayer engineered composite fiber structure is used to form a helmet, particularly for military ballistic resistant applications, the overall thickness of the helmet is preferably between about 0.250 inches to about 0.450 inches, preferably between about 0.275 to about 0.360 inches.

A preferred embodiment of the present invention is further directed to a military ballistic resistant helmet shown in Figure 1 having at least one layer of a 3-D woven material combined with a second 2-D material layer, both of which include at least one array of high performance, substantially unidirectionally-oriented fibers, more preferably having a second array of high performance, substantially unidirectionally-oriented fibers cross-plied at an angle with respect to the first array of fibers or interwoven therewith in a traditional, woven fabric, and laminated to the first array of fibers via the use of adhesives and/or bonding agents.

Referring now to figures 3 and 4, a sporting goods application of a contoured laminated multilayer composite fiber structure is shown, generally referenced 30. In particular, the contoured shape forms a canoe or boat having at least one opening 31 into which a person can be positioned for operating the boat.

The preferred embodiment forming a boat or canoe is advantageously constructed from a combination of high performance fibers selected from the group consisting of Kevlar, fiberglass, carbon, Vectran, and the like, and combinations thereof. In one prototype, the at least one 3-D fabric used to form the canoe embodiment was constructed of a combination of 3-D and 2-D woven materials using Kevlar129, fiberglass, and carbon fibers. Also, the combinations may be used in particular to provide reinforcement via stiffening ribs that run crosswise (shown as direction A in Figure 3). In particular, Kevlar 129 was used in a 3-D woven fabric at 2.5 density and two layers of that fabric were used to form the base or hull 32 of the boat. The process used for forming the composite from these fabric combinations was a closed-mold vacuum resin transfer molding (VARTM) method. While an open-mold process may be used, environmental concerns as well as optimized processing make the closed-mold method more desirable. Prior to setting the material(s) into the mold, it is possible to pre-wet the fabric with a resin, although this is not necessary in most cases to achieve adequate saturation of the matierals. Additional materials, including but not limited to wood, particularly balsa wood, may be combined with the material(s) in the mold, in the centerline along the boat length or crosswise for stability and stiffness. Also, foam may be advantageously incorporated into cross-wise stiffening ribs to increase the bending moment in that direction. After the fabric is set into the mold, then resin is forced throughout the materials in the mold, and any excess resin is removed via vacuum. The resin used in the prototype was a Reichold resin that was cured overnight (about 24 hours) in ambient conditions.

Finished composite top and bottom sections (e.g., cut along line X-X in Figure 4), are joined via stitching or wiring or otherwise adhering and sealing together; in the prototype, the top and bottom sections were joined together by wire that was run through drilled holes in each section and then twisted together. Additional sealant may be provided by fiberglass taping or covering of the joints. Finally, sanding or other smoothing of the surfaces may be done to provide a smooth surface finish. Also, gel coatings may be applied to further enhance the surface smoothness and to provide less resistance and drag in the water.

The present invention is further directed to a method for forming a contoured laminated multilayer composite fiber structure for protective body armor and/or sporting goods applications including the steps of providing at least one 3-D engineered fiber structure, molding or otherwise manipulating the structure to produce a predetermined contour shape, and treating and stabilizing the structure via heat and/or pressure. An additional step may include introducing a resin into the at least one 3-D engineered fiber structure prior to molding the structure. Another step may include providing at least one two-dimensional engineered fabric laminated with the at least one 3-D engineered fabric prior to molding or otherwise manipulating the multilayer laminate into a predetermined contoured shape. Still another additional step may include applying a finish to the surface of the contoured laminated multilayer composite fiber structure after it has been stabilized. The finish may include water-resistant finish, water-repellant finish, scratch-resistant finish, shine-resistance, shine enhancer, wax, color, and the like, depending upon the application for which the finished structure will be used.

Additional applications include using the contoured laminated multilayer composite fiber structure for forming the body of a cooler. In this application, insulating material may be introduced within or between the multilayer fabrics for ensuring that goods stored within the cooler will retain their initial temperature.

Certain modifications and improvements will occur to those skilled in the art upon a reading of the foregoing description but are not included for the sake of conciseness. It should be understood that all such modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the following claims.

The present invention may, of course, be carried out in other specific ways than those set forth without departing from the spirit and essential characteristics of such invention. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

CLAIMS

We claim:

1. A contoured laminated multilayer composite fiber structure comprising:

at least one three-dimensional engineered fiber structure manipulated to form a contoured shape for providing uniform structure surface without having creasing or folding in contoured regions, thereby providing substantially uniform structure performance and characteristics throughout all regions of the structure.

2. The contoured laminated multilayer composite fiber structure according to claim 1, further including at least one high performance fiber array within the at least one three-dimensional engineered fiber structure.

3. The contoured laminated multilayer composite fiber structure according to claim 2, wherein the high performance fiber array is selected from the group consisting of Kevlar, carbon, fiberglass, and combinations thereof.

4. The contoured laminated multilayer composite fiber structure according to claim 1, further including a resin that is introduced into and saturating the structure and cured for providing increased dimensional stability and strength.

5. A method for forming a composite multilayer laminated structure for use in protective body armor and sporting goods comprising the steps of:

providing at least one 3-D engineered fiber structure;

manipulating the at least one 3-D engineered fiber structure to form a predetermined contoured shape; layering the structures and

stabilizing the structure in the predetermined contoured shape.

6. A composite multilayer laminated structure for forming a floatation device comprising at least one three-dimensional engineered fiber structure manipulated to form a contoured shape and a resin introduced to impregnate the at least one three-dimensional engineered fiber structure, the resin being treated and cured after the structure has been shaped and contoured for providing a rigid, uniform structure surface without having creasing or folding in contoured regions, thereby providing substantially uniform structure performance and characteristics throughout all regions of the structure.

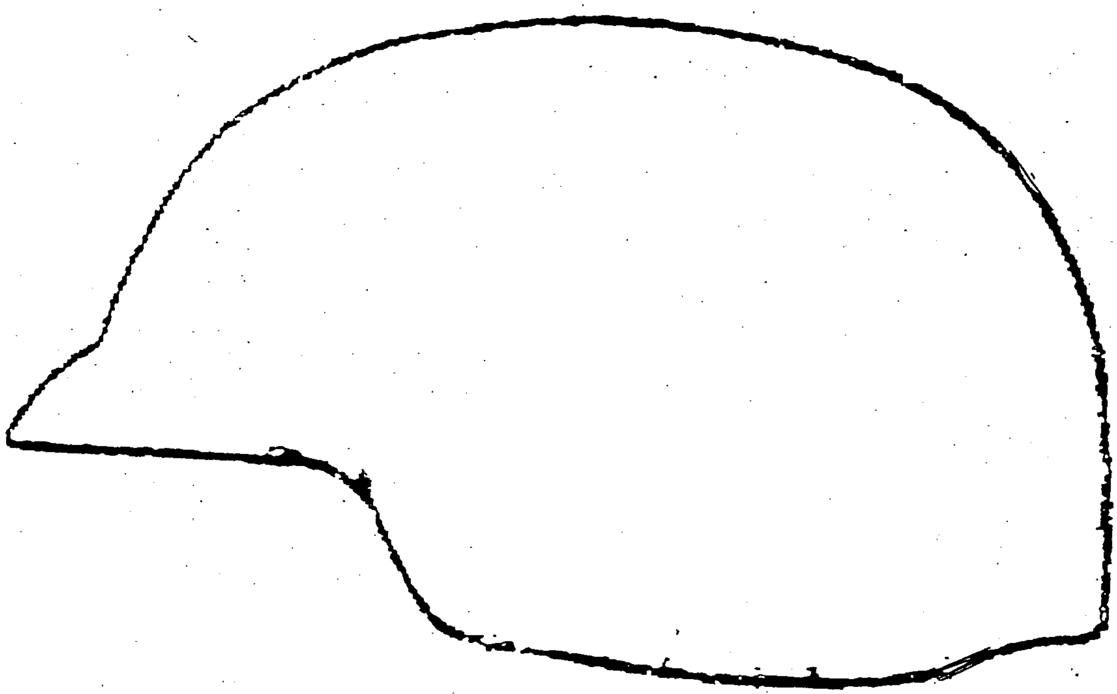

FIGURE 1

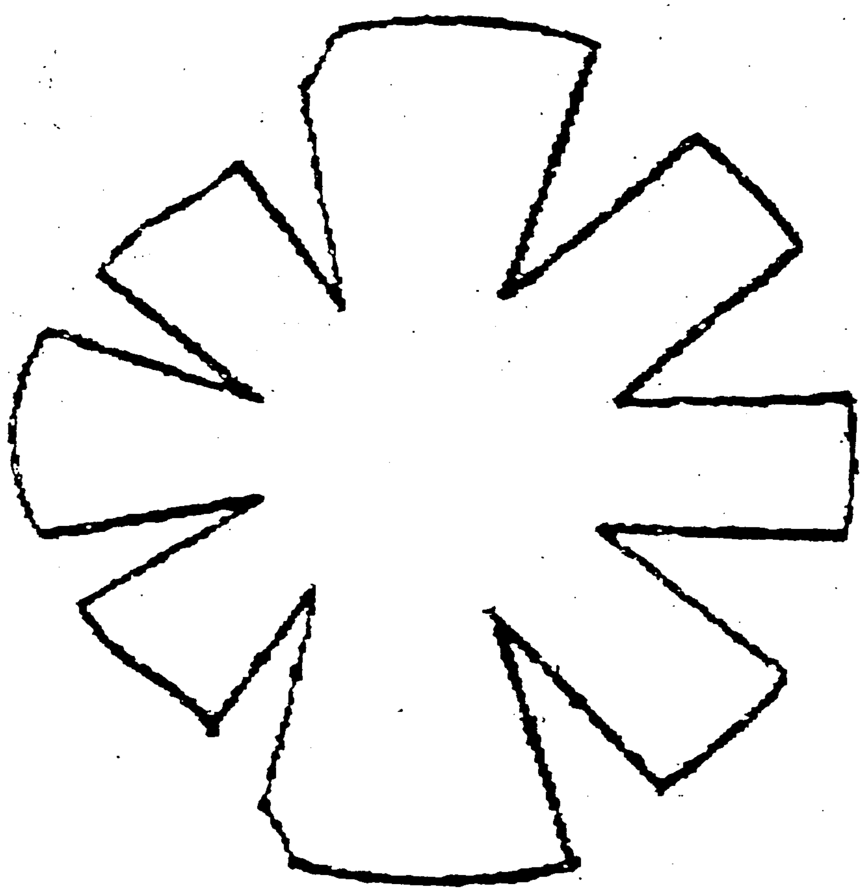

FIGURE 2

PRIOR ART

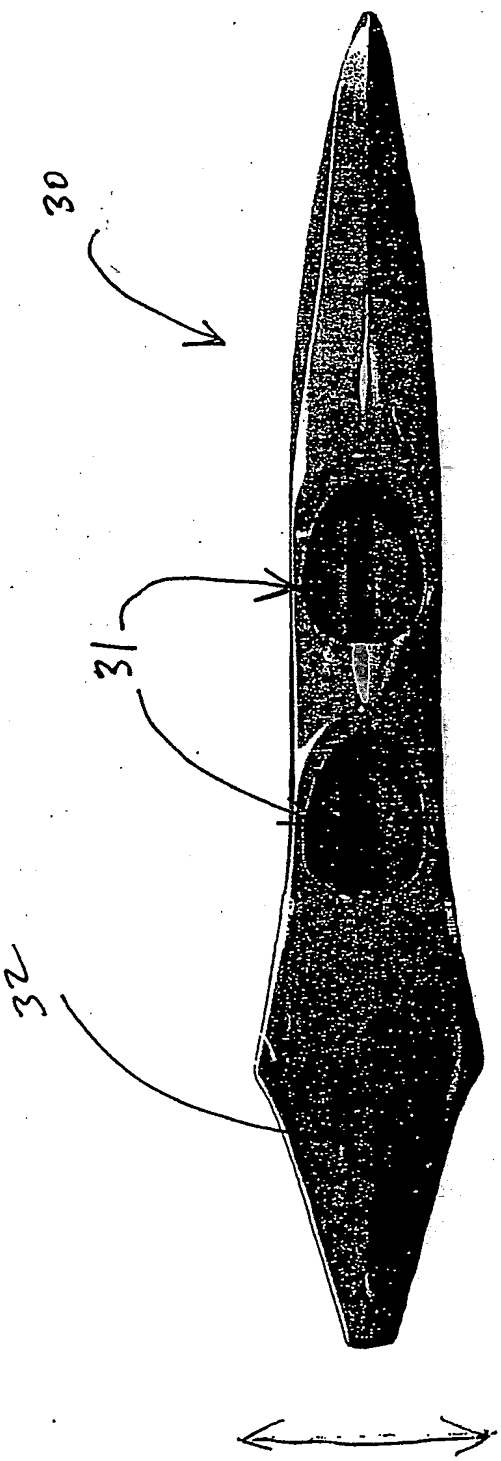

FIGURE 3

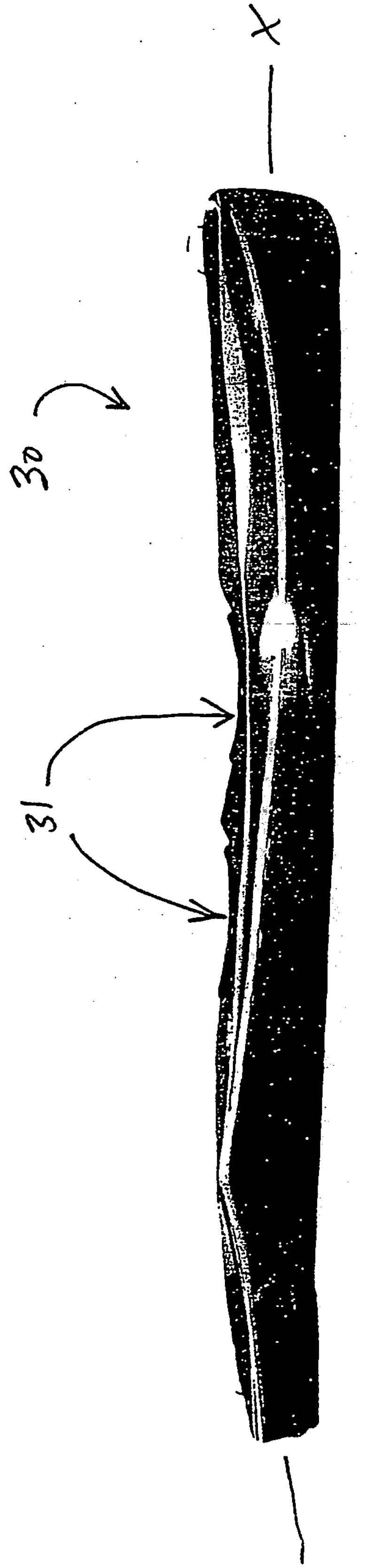

FIGURE 4

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(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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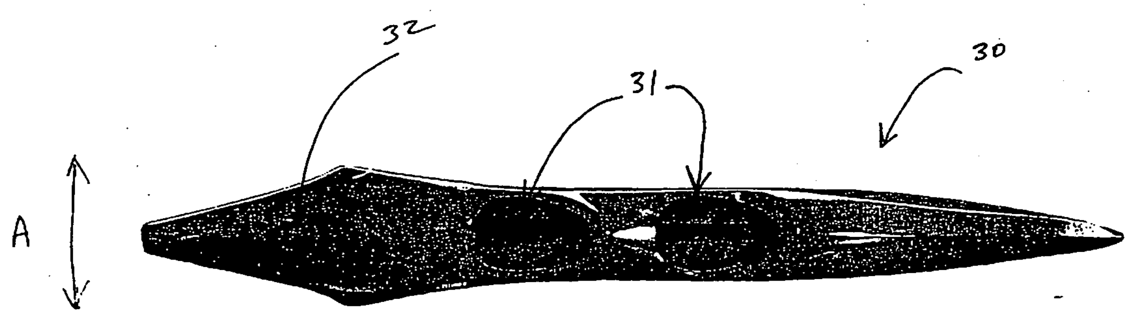

(57) Abstract: A contoured multilayer laminated composite structure (30) having uniform surface area before, during, and after processing, thereby providing improved and uniform finished product characteristics and performances for protective body armor and/or sporting goods applications. The contoured rigid laminated structure (30) of the present invention provides increased impact resistance, resistance to delamination, shear resistance, strength, and overall performance due to the uninterrupted dissipation of energy spread throughout the entire surface area of the fabric and the uniform surface area presented in the finished product.

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B32B 5/08
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B. FIELDS SEARCHED

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U.S. : 428/113,174,212,911,105,175; 89/36.01,36.02,36.12; 2/6.6,412

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,112,667 A (LI et al) 12 May 1992 (12.05.1992), entire document.	1-4, 6
A	US 5,075,904 A (SHIRASAKI et al) 31 December 1991 (31.12.1991), entire document.	1-6
A	US 4,953,234 A (LI et al) 04 September 1990 (4.09.1990), entire document.	1-6
A	US 4,737,402 A (HARPELL et al) 12 April 1988 (12.04.1988), entire document.	1-6

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:

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